A *BVI* Photometric Study of the Near-Galactic Center Globular Cluster NGC 6517 (C1759-089)

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ABSTRACT

We present the results of a *BVI* photometric study of the globular cluster NGC 6517 using CCD images obtained at the prime focus of the CFHT. From the resultant color-magnitude diagram, we infer that the cluster is differentially reddened and develop a method for determining the amplitude of this effect, which amounts to ~ 0.4 mag in $(V - I)$ across our ~ 4 arc-min field. From the corrected V_0, $(V - I)_0$ color-magnitude diagram, we derive the metallicity and distance modulus of the cluster. Our values for the mean foreground reddening ($E(B - V) = 1.10 \pm 0.10$) and metallicity ([Fe/H] = -1.58 $\pm$ 0.05) agree to within uncertainties with previous determinations. Our apparent distance modulus of 18.3 ± 0.2, however, is larger than the sole previous determination. When the distance modulus is corrected for absorption, assuming that $R_V = 3.8$ for this line of sight, we find that NGC 6517 is within 3 kpc of the Galactic center, making it a bulge member. This makes NGC 6517 only the fourth metal poor cluster in the bulge for which an accurate CMD is available.

Subject headings: globular clusters, Galactic structure

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1. Introduction

How the Galaxy formed is one of the most debated questions in astronomy today. As a result of an improved understanding of stellar evolution and better observations of the stellar populations of the Galaxy, early models of galaxy formation, such as the Eggen, Lynden-Bell, & Sandage (1962) picture, have been amended to the more recent versions of Searle & Zinn (1978) and Lin & Murray (1991). Major constraints on these theories are derived from observations of the globular cluster system (GCS) of the Galaxy.

The GCS has two principal components (Morgan, 1959; Harris, 1976; Searle & Zinn, 1978 and Zinn, 1985). The *disk* subsystem is somewhat flattened, with typical rotational velocities about the galactic center of $\sim$ 170 km/s; the disk clusters are metal-richer than $[Fe/H] = -0.8$ (Armandroff, 1989). The *halo* subsystem of clusters rotates more slowly, at $V_{rot} \approx 45$ km/s, and consists of the metal-poor clusters, $[Fe/H] < -0.8$. The halo subsystem is sometimes further subdivided into an inner halo, with $R_{GC} < 7kpc$, and an outer halo, for which $R_{GC} > 7kpc$. For a complete review of the globular cluster system of the Galaxy see Zinn, 1985 and Armandroff, 1989, and references therein.

A thorough study of the globular cluster system is essential, therefore, if any conclusions about the formation of the Galaxy are safely to be drawn. Prior to 1990, however, no accurate CMDs had been published for halo clusters within $\sim$ 3 kpc of the galactic center (Janes & Heasley, 1991). It has been suggested, on the basis of rough distance estimates, that NGC 6517 is such a cluster: see Section 2. Moreover, NGC 6517 is known to be of intermediate-to-low metallicity, and it is consequently an especially interesting object for closer scrutiny as an inner halo object. Only recently, however, with the combination of charge coupled devices (CCDs), specialized image processing packages, and excellent seeing, have the necessary studies of extremely crowded objects like NGC 6517 become possible. Without observations of such inner halo clusters our understanding of the globular cluster system will remain incomplete.

This paper will take the following form: In Section 2, previous observations of NGC 6517 are presented, along with a review of determinations of the cluster's distance and metallicity. In Section 3 we describe our own observations, the initial stages of the data reduction, and our calibration. In Section 3.3, the particular question of reddening is addressed. It is apparent from the width of the CMD that NGC 6517 is differentially reddened. Further evidence for this conclusion, as well as a rough modeling of the effect, are presented and quantified. In Section 4, we present the corrected CMD for NGC 6517, derive the distance and metallicity of the cluster, and compare our results to earlier determinations. Finally, in Section 5, we summarize our principal findings.

2. Previous Observations

In Table 1 we list the heliocentric position, the galactocentric distance, and some of the characteristics of NGC 6517. All the values are from Webbink's (1985) tabulation, except the radial velocity, which is from Zinn (1985) . The quoted galactocentric distance assumes $R_o = 8.8$ kpc and V(HB) = 18.0; the present study leads to revision of this value (see Section 5). Figure 1 is a reproduction of a CCD frame of NGC 6517 taken through the V filter. At the prime focus of the CFHT, the 640 x 1024 RCA4 CCD which we used has a scale of 0.22 arc-sec/pixel and a field of 2.35 x 3.76 arc min. The readnoise of the chip was $\sim 64e^-$.

Fig. 1.— A 60s V image of NGC 6517 taken at the CFHT. North is to the top, and East to the left; the field is 2.35 x 3.76 arc-min.

We now briefly review earlier photometric and spectroscopic studies of the cluster.

Integrated colors for NGC 6517 have been obtained by Kron & Mayall (1960) in the BPI system, and by Harris & van den Bergh (1974), Zajtseva et al. (1974) and Racine (1975) in the UBV system, with

Table 1: Properties of NGC 6517

α_{1950}	17 59 06
δ_{1950}	-08 57.6
ℓ	019.225
b	+06.762
R_{GC}	$\sim 3.8kpc$
V_{radial}	$-47km/s$
M_V	-7.10

Table 2: Previous observations of NGC 6517.

Author(s)	$(B-V)$	$(U-B)$	$E(B-V)$	$(m-M)_V$	[Fe/H]
Kron & Mayall, 1960	1.75				
Harris & van den Bergh, 1974	1.80	0.81	1.14[a]		
Zajtseva et al., 1974	1.79	0.98	1.07[a]		
Racine, 1975	1.75	0.88	1.05[a]		
Harris, 1975			1.0	18.1[b]	
Harris, 1980				17.4[c]	
Bica & Pastoriza, 1983	1.76		1.11		-2.18 ± 0.4
Zinn & West, 1984					-1.34 ± 0.15
Zinn, 1985			1.08	17.09[d]	
Armandroff, 1989				17.35[e]	

Notes to Table 2

[a] Reddening determined using Racine's (1973) intrinsic relation for globular cluster $(B-V)$, $(U-B)$ colors

[b] $M_V(\mathrm{HB}) = 0.6$ (Sandage, 1970)

[c] Distance modulus re-estimated by Harris following reexamination of the original plate material (Harris 1975).

[d] $M_V(\mathrm{HB}) = 0.35 * ([Fe/H] - (-1.66)) + 0.8$ (Sandage, 1982)

[e] $M_V(\mathrm{HB}) = 0.20 * ([Fe/H] - (-2.3)) + 0.46$ (Lee et al., 1987)

the results as summarized in Table 2.

The only previous CMD of NGC 6517 was constructed by Harris (1975) as part of a B,V photographic investigation of 12 southern galactic globulars, using the 0.6-m University of Toronto telescope at Las Campanas Observatory. Plate limits of $V \approx 18$ and $B \approx 19$ were reached. In his description of the cluster, Harris states "As well as being small, distant and highly reddened, this difficult object is compact...". As a result of the high background, the severe crowding, and the compactness of the cluster, the $(B-V)$ colors were not reliable below $V \approx 17$. These very shallow limits made a direct determination of the distance to NGC 6517 from its horizontal branch (HB) impossible.

However, Harris inferred a horizontal branch apparent magnitude of $V = 18.7$ for the cluster by intercomparing its giant branch (GB) with those of other clusters of the same spectral type and relying on previous determinations of GB height as a function of spectral type (Sandage & Wallerstein, 1960).

Bica & Pastoriza (1983) included NGC 6517 in a survey of 91 galactic globulars observed both with DDO and with UBV filters. Although there were many discrepancies in the metal-poor ([Fe/H] $<$

-1.5) range, they found that their integrated DDO colors correlated with the existing metallicity determinations for many of the clusters in their survey; consequently, they were able to use the DDO colors to predict reddenings in UBV. Their determinations of [Fe/H], $E(B-V)$, and $(B-V)$ for NGC 6517 are given in Table 2.

Zinn & West (1984) included NGC 6517 in a survey of integrated cluster spectra. Their method of determining metallicities relies upon the size of the Q_{39} index (Zinn, 1980), a measure of the strength of the Ca H and K features in a globular cluster's integrated spectrum. Zinn (1985) also found that Q_{39} correlated well with the integrated $(B-V)_0$ colors, and used previous determinations of the color of NGC 6517 to derive the reddening (Table 2).

An examination of Table 2 reveals that the estimates of reddening for NGC 6517 are broadly consistent between authors. A straight mean of those reddening values in Table 2 that were derived using the intrinsic color-color relation of Racine (1973) is $E(B-V) = 1.09$. This value is in excellent agreement with that found spectroscopically by Zinn (1985). In contrast, there are only two determinations of [Fe/H], and there is a large discrepancy between them.

Table 2 lists various determinations of the apparent distance modulus in V, but it must be emphasized that, even though these estimates differ, *all* of the values rely on Harris's (1975) original CMD for the cluster. In that paper, Harris estimated the tip of the giant branch (GB) to lie at $V = 16$, and took the HB to lie $\Delta V = 2.7$ mag fainter; in this way, he deduced $V(\mathrm{HB}) = 18.7$. In a later work, however, Harris (1980) revised his estimate of $V(\mathrm{HB})$ from 18.7 to 18.0, upon a re-examination of the cluster's red giant branch (RGB). Using this revised $V(\mathrm{HB})$, Zinn (1984) and Armandroff (1989) calculated the distance modulus of NGC 6517 on the basis of two different relations between the absolute magnitude of the HB and the cluster metallicity (see the footnotes to Table 2). We shall return to this point when we carry out our own distance determination in section 4.1.

3. New Observations and Analysis

Our observations were carried out as part of two separate runs in May 1990 at the prime focus of the 3.6-m Canada-France-Hawaii Telescope (CFHT). These observations were made with the RCA4 CCD and a BVI filter set designed to match the standard system. Standard stars from those tabulated by Landolt (1983) and Christian et al. (1985) were observed each night to provide calibration.

Historically, globular cluster CMDs have been constructed in the $(B-V)$, V plane. However, NGC 6517 is a heavily reddened object and B filter exposures would be uneconomical as they would require very long exposure times. For this reason, we decided to use the I filter. Indeed recent work (Da Costa & Armandroff, 1990) has has shown that the $(V-I)$ color is very useful in determining cluster metallicities. Nevertheless, in addition to our V and I exposures, we did secure a series of short B images in order that an estimate of the reddening could be made from a color-color diagram.

In Table 3 we summarize the important features of the observing sessions. On the night of May 21 (m21 hereafter), the seeing during our observations of NGC 6517 was extremely good to begin with, $0.6''$, but worsened steadily: by the time the second set of V images was being taken it had deteriorated to $1.4''$. The effects of crowding make the attainable precision very sensitive to the seeing, so we chose simply to reject the last six frames in V and the last three in I as they provided negligible improvement to the signal-

to-noise. The data from May 28 (m28) consists of 11 B frames, one in V, and one in I, with the last two taken to test the consistency of the photometry from the m21 night.

3.1. Reduction of Standards

The standard star observations were reduced with the DAOPHOT package in IRAF[1]. The instrumental magnitudes were transformed to the standard system using equations of the form:

$$m - M = \alpha * C + \kappa * X + \gamma \qquad (1)$$

$$c = \alpha * C + \kappa * X + \gamma \qquad (2)$$

where m, M, c, C are respectively the instrumental and standard magnitudes and colors. Unfortunately, there were an insufficient number of observations of standard stars at large airmass to allow an accurate determination of the extinction term. For this reason we adopted for the extinction coefficients an average of values typical of the CFHT site in previous observing runs. The adopted and derived coefficients - along with the "notional" values for the CFHT - are given in Table 4. The random scatter in the photometry of the standards is typically ± 0.04 magnitude.

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[1] IRAF: the Image Reduction and Analysis Facility is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation (NSF).

Table 3: Observing log for program field, both nights.

Night	Exposure(s)	Filter	Seeing	Airmass
m21	3x100	V	$0.6''$	1.207
m21	6x100	I	$0.6''$	1.223
m21	6x100	V	$1.4''$	1.258
m21	3x100	I	$1.4''$	1.301
m28	60	B	$0.6''$	1.205
m28	10x100	B	$0.6''$	1.210
m28	60	V	$0.6''$	1.328
m28	60	I	$0.6''$	1.339

3.2. The Program Frames

All of our exposures were found to be read-noise dominated, which suggests that they should be averaged; this was done for the B frames from the m28 night. For the m21 night, however, variations in the point spread function (PSF) between the frames would have made this averaging unreliable. For this reason, the m21 frames in best seeing were simply registered and co-added. All frames were then reduced using the DAOPHOT PSF fitting package in IRAF.[2] Finally, the aperture corrections needed to tie the zero-point of the PSF magnitudes to the standard system were determined to a precision of ±0.03 magnitudes.

In the NGC 6517 photometry, we find no important zero-point differences between the V and I scales on the two nights, and no scale errors as a function of magnitude. In combining the photometry from the two nights we reduced the m21 V and I photometry to the m28 scales, for it was on the later night that the photometric standards yielded a better fit.

3.3. Reddening

Our observations are tied to the standard system of Cousins, in which color excesses are related by (Dean et al., 1978)

$$\frac{E(V-I)}{E(B-V)} = [1.00 + 0.06 * (B-V)_0 \\ + 0.014 * E(B-V)]$$

For typical RGB stars, $(B-V)_0 = 1.2$, and for NGC 6517 in particular earlier estimates of the mean foreground reddening yield $E(B-V) \approx 1.1$ (Table 2); this implies $E(V-I)/E(B-V) = 1.36$ for the RGB stars in NGC 6517. In order to translate the reddening into an absorption and thus determine the absolute distance modulus it is necessary to make some assumption about the value of the ratio of total to selective absorption ($R_V = A(V)/E(B-V)$). The correct value of R_V is dependent on the nature of the material which is absorbing the light. For the diffuse interstellar medium $R_V = 3.1$ is reasonable but within areas of dense clouds a value of $R_V = 5$ is more appropriate (Cardelli et al., 1989).

Before a reconsideration of the total mean absorption in the direction of NGC 6517, however, we first consider the possibility that the cluster is *differentially* reddened.

3.3.1. Differential Reddening

In Figure 2 we present a CMD in V, $V-I$, which shows at once that the GB is very broad in comparison with typical cluster GBs (see for example Hesser, 1988). There are two possible explanations: first, the cluster could have a large spread in metallicity; or second, the cluster could be differentially reddened. A spread in metallicity of 0.8 dex would be required to explain the width of the GB[3]; this seems implausible. Only a few clusters display a spread of metallicity in their member stars, the best-known example being $\omega\,Cen$ (Bell et al., 1981); for this cluster the spread is $\Delta[Fe/H] \approx 0.5$. Moreover, more than half of the foreground reddening of NGC 6517 is caused by a single cloud complex, with the remaining reddening caused by a dense OH cloud (Sandell et al., 1987). Given the cluster's proximity to the galactic center and the evident clumpiness of the foreground material, spatially variable absorption seems likely. Indeed we shall now show via a direct test that this is the case.

In our determination of the presence of differential reddening which follows, we adopted values of R_V ranging from $R_V = 2.5$ to $R_V = 5$. The value of $R_V = 3.8$ provided the best improvement in the test which we now describe.

In order to determine the nature of this differential reddening we examined the way in which the mean $V-I$ color of the RGB stars varies with spatial position on the sky. To accomplish this, we segmented the image into a 3 by 3 grid, with stars less than $25''$ from the center of the cluster excluded. The mean color for all the RGB stars brighter than $V = 18.5$ was calculated; this revealed that stars in the northeast quadrant of the frame are bluer in the mean than stars in the southwest. This is consistent with the presence of a Lynds dark cloud to the southwest of the cluster (Sandell et al., 1987). The exact nature of the variation in the reddening is most likely very complex. However, we chose to approximate it as a linear gradient across the field. In order to quantify this variation, the following procedure was adopted:

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[2]Our complete star list (in APPHOT format) along with copies of our combined B, V and I images are available via anonymous ftp to Astro.QueensU.CA.

[3] Based on the $(V-I)_{0,-3}$ to [Fe/H] relation (Da Costa & Armandroff, 1990).
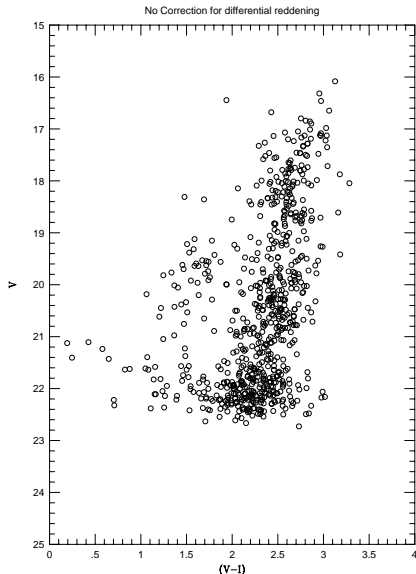
No Correction for differential reddening

Fig. 2.— The raw CMD. Stars with $V < 18$ are from m28; all other stars are from m21. No stars within $25''$ of the cluster center or with $\sigma_{(V-I)} > 0.10$ are included. Note that the lack of points in the region $18.7 < V < 19.1$ is caused by an undersampling of the CMD in this region. Stars which are brighter than $V \approx 19$ are saturated on the m21 frames while stars fainter than this have less reliable photometry on the m28 night. These effects conspire to give an underpopulation in this area of the CMD.

1. A mean RGB sequence was fit to the ensemble of points in the V, $(V-I)$ plane. The offsets of points from this sequence, along reddening trajectories, were determined for stars spanning a limited range of the RGB. (We will refer to these offset values as δ.)

2. A rectangular coordinate grid was set up across the image in an arbitrary orientation.

3. The δ values were fit as a linear function of x position.

4. From this fit, positionally dependent reddening corrections were calculated for and applied to all stars in the field, and a re-

vised CMD was plotted. Within the CMD the width of the giant branch (i.e. the spread of points about the mean color as a function of V magnitude) was calculated.

5. The process was repeated with systematic iterations through various position angles of our coordinate grid. The minimum width of the RGB is expected to come, of course, when the x-axis lies along the true gradient of the reddening.

In Figure 3, we show the results of this experiment. There is a clear minimum near an angle of 70° on our coordinate system (which corresponds to 20° *west* of *north* on the sky), with an amplitude of $E(V-I) \sim 0.4$ from corner to corner.
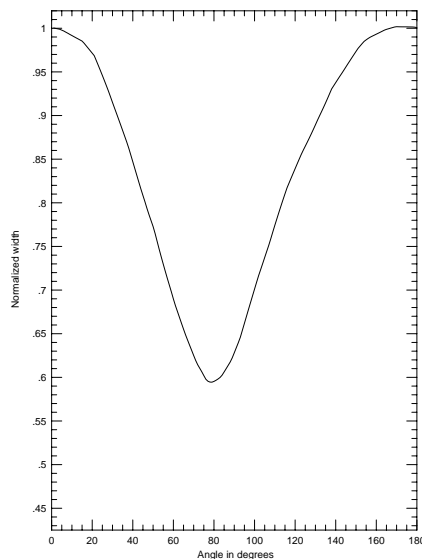

Fig. 3.— Normalized width of the giant branch as a function of the orientation of the assumed linear gradient in the differential reddening, as described in the text.

Figure 4 shows the CMD after the data were corrected for the differential reddening. In the figure, the data have been corrected for the *average differential* effect: that is, the scales are as would be observed at the cluster center.

It is worth emphasizing that the experiment just described relies on changes in the width of the RGB
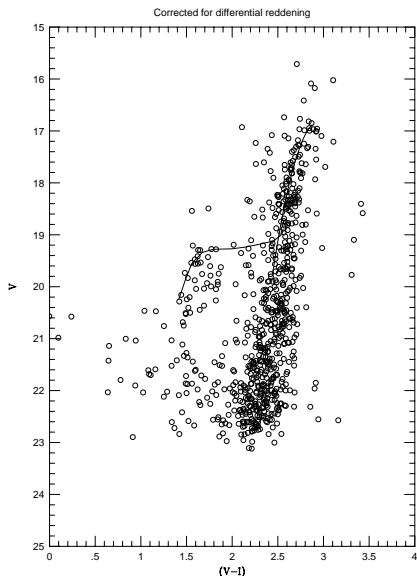
6

Fig. 4.— The CMD for NGC 6517 corrected for the effects of variable interstellar obscuration. Stars with $V < 18.7$ are from m28; all other stars are from m21. No stars within $25''$ of the cluster center or with $\sigma_{(V-I)} > 0.10$ are included. The RGB and HB are plotted as fiducial lines chosen to reflect the most likely positions of the unobscured RGB and HB.

between $17 < V < 18$ but that the distribution of points in the corrected figure is manifestly tightened over a much larger range; this speaks well for the correctness of the model. Moreover, it is clear that differential reddening rather than a metallicity spread must be responsible for the scatter of data in the raw CMD.

3.3.2. A Reconsideration of the Global Reddening

Figure 5 shows the $(B - V)$, $(V - I)$ color-color plot after the correction for differential reddening. The *mean* foreground reddening for NGC 6517 was determined from a comparison of the RGB sequence in this plot to those for the clusters NGC 1851 and NGC 7078, data for which are also shown in the figure (Da Costa & Armandroff, 1990 and Stetson, 1981). NGC 1851 and NGC 7078 were used as comparators because the reddenings of these clusters are well determined and their metallicities, [Fe/H] =-1.29

and [Fe/H] =−2.17 respectively (Da Costa & Armandroff, 1990), bracket the previous determinations of the metallicity of NGC 6517.
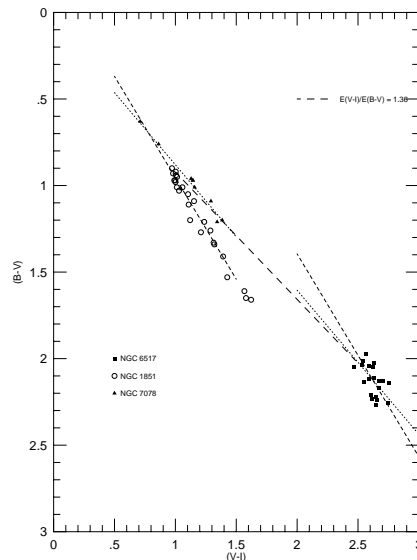

Fig. 5.— Two-color plot of the GB of NGC 6517 compared to the dereddened GB of NGC 1851 and NGC 7078. A line has been fitted to both data sets and both lines shifted along the reddening trajectory (shown as a dashed line) to best fit the NGC 6517 data.

Straight lines were fit through the RGB of the two comparison clusters and lines with the same slopes were fit, in turn, to the NGC 6517 RGB. The zero-point offsets along the reddening trajectories were determined. The global reddening was then taken as the average of the reddenings implied by these offsets. From this procedure we determine that for NGC 6517 $E(B-V) = 1.05 \pm 0.15$ implying that $A_V = 4.0 \pm 0.6$.

Figure 6 gives the final fully corrected CMD for NGC 6517. The superposed fiducial is a hand-drawn line to best represent the position of the cluster's RGB. The apparent width of the RGB cannot be attributed to photometric uncertainties alone and is likely due to residual differential obscuration, which is presumed to be patchy on small scales.

Table 4: Coefficients for the transformation of instrumental *bvi* magnitudes to the standard system. Also given are the CFHT notional values.

Coeff.	m21	m28	CFHT
α_I	0.029	0.030	
κ	$\cdots$	$\cdots$	0.091
γ	1.247	1.301	
$\alpha_{(V-I)}$	0.050	0.027	
κ	$\cdots$	$\cdots$	0.164
γ	0.505	0.522	
$\alpha_{(B-V)}$	$\cdots$	0.852	
κ	$\cdots$	$\cdots$	0.07
γ	$\cdots$	0.126	
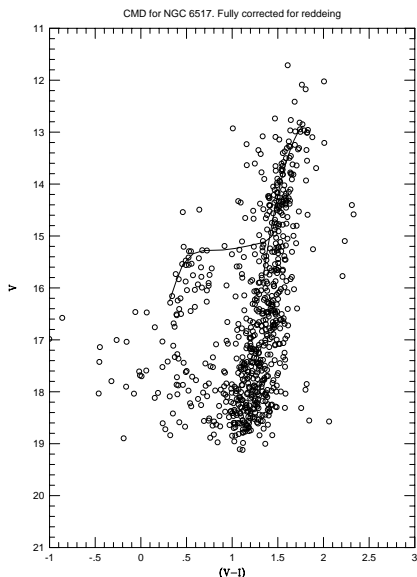
Fig. 6.— The CMD for NGC 6517 fully corrected for obscuration.

4. Interpretation

In recent years, refinements in theory have made it possible to follow the stellar evolution of globular cluster stars from the main sequence to the end of the HB phase, although the evolution from the GB to the HB is still only phenomenological. These theoretical models make it possible to analyse the CMD for abundance ratio and age effects (see for example Vandenberg & Stetson, 1991; Lee et al., 1987 and Vandenberg et al., 1990). However, there remains a great deal of uncertainty in the zero point of the age scales and the precise evolution of the member stars in these models. In what follows, therefore, we prefer to compare the CMD of NGC 6517 to those of several clusters of similar composition, thereby avoiding some of the problems of scale calibration.

4.1. The Metallicity

Recent work has shown that when the distance modulus and reddening are known it is possible to determine the metallicity of a cluster using a cubic relation between the $(V - I)$ color of the RGB (read at a fixed I absolute magnitude) and cluster metallicity (Da Costa & Armandroff, 1990). The width of our RGB for NGC 6517 makes accurate determinations of the fiducial sequence and reddening difficult. For this reason we do not employ the method developed by Da Costa & Armandroff (1990). We instead rely on the slope, S, of the RGB as our indicator of metallicity. This method has the advantage of being independent of reddening and providing a simple one-step estimate of the metallicity.

Originally the S parameter (Hartwick, 1968) was established in the $V, (B - V)$ system. In order to use it here we have calibrated the $S_{(V-I)}$, [Fe/H] relation using the clusters tabulated in Da Costa & Armandroff (1990). We define $S_{(V-I)}$ as the slope of the RGB from the level of the HB to a point 2.3 magnitudes higher. The results of our calibration are given in Table 5. An unweighted linear regression yields

$$[\text{Fe/H}] = 6.78 \times 10^{-2} - 2.561 \times 10^{-1} \times S_{(V-I)} \pm 0.06.$$

From Figure 6 the color of the RGB 2.3 magnitudes above the HB is $(V - I) = 2.9 \pm 0.1$ and $(V - I)_{\text{HB}} = 2.55 \pm 0.1$; thus $S_{(V-I)} = 6.57 \pm 0.15$, and we deduce that $[\text{Fe/H}] = -1.62 \pm .06$.

Sarajedini (1994) has shown that it is possible to determine both [Fe/H] and $E(V - I)$ simultaneously

Table 5: S parameter relation for $(V - I)$, all metallicities are from Da Costa & Armandroff (1990).

Cluster	[Fe/H]	$S_{(V-I)}$
NGC 7078	-2.17	8.31
NGC 6397	-1.91	7.72
NGC 7089	-1.58	6.93
NGC 6752	-1.54	6.30
NGC 1851	-1.29	4.93
NGC 104	-0.71	3.04

from a V, $(V - I)$ CMD. Using this technique we find that $[\text{Fe/H}] = -1.55 \pm 0.15$ and $E(V - I) = 1.55 \pm 0.15$ with the uncertainty resulting from the width of the RGB and the uncertainty in the position of the HB. These values agree, within the quoted uncertainties, with those determined using the slope of the RGB and the offset of the RGB in the two-color plot.

The use of these two methods provides an internal consistency check on the RGB as they are both calibrated using same data sets but rely on slightly different parts of the RGB. The agreement of the two estimates of metallicity suggests that the RGB has been reasonably well determined and that $[\text{Fe/H}] = -1.58 \pm 0.05$. Similarly the two estimates of the reddening yield very good agreement suggesting that $E(B - V) = 1.10 \pm 0.10$ and thus $E(V - I) = 1.50 \pm 0.10$

4.2. The Distance Modulus

Estimates of the distance modulus are hampered by the continuing controversy over the metallicity dependence of the absolute magnitude of the HB. In Table 2, for example, two of the relations which were used to determine the distance to NGC 6517 result in distance moduli differing by 0.26 magnitudes for the same input parameters. In this paper, we will rely on a recent determination which takes into account revisions in the oxygen abundances and in opacity tables (Dorman, 1992 and Bergbusch & Vandenberg, 1992).

From our differentially corrected CMD, Figure 4, we estimate the magnitude of the HB to be $V(\text{HB}) = 19.3 \pm 0.10$ which, when combined with our adopted reddening of $E(B - V) = 1.15 \pm 0.10$ and $R_V = 3.8$, yields

$$V(\text{HB})_0 = 14.9 \pm 0.15.$$

From the previous section we adopt a metallicity of $[\text{Fe/H}] = -1.58 \pm 0.05$ for the cluster, and using

$$M_V = 0.15[\text{Fe/H}] + 0.83 \qquad (3)$$

(Dorman, 1992) derive an absolute magnitude of the HB of

$$M_V(\text{HB}) = 0.60 \pm 0.03.$$

We conclude that the absolute distance modulus of NGC 6517 is

$$(m - M)_0 = 14.3 \pm 0.2,$$

implying that the cluster is more distant than has heretofore been realized. We will return to this point in our concluding discussion.
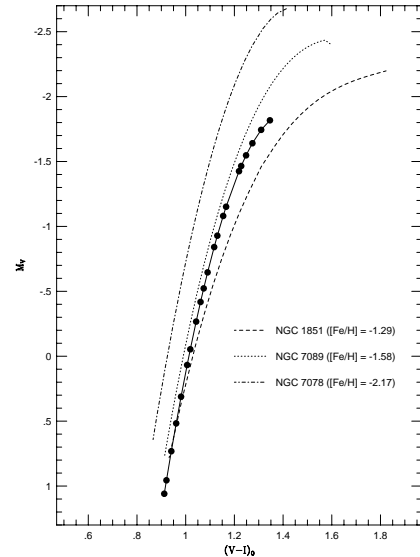

Fig. 7.— The giant branch plotted as fiducial points chosen to reflect the most likely position of the unobscured RGB on the absolute scale. Also shown are three RGBs with comparable metallicities, (Da Costa & Armandroff, 1990)

5. Summary and Conclusions

Our principal conclusions are the following:

- NGC 6517 is differentially reddened with an amplitude of $E(V - I) \sim 0.4$ across our ~ 4 arcmin field. The gradient in the reddening is spatially consistent with the known clumpiness in

the cloud distribution in the direction of NGC 6517.

- The mean foreground reddening we derive, $E(B-V) = 1.10 \pm 0.05$, is consistent with values obtained by other authors in earlier studies.

- The absolute distance modulus we find for NGC 6517, $(m-M)_o = 14.3 \pm 0.2$, is larger than the rough value estimated by Harris (1975): his *apparent* distance modulus in V, 18.1, combined with the foreground absorption of $A_V = 4.0$ yields a true distance modulus of 14.1. Of course, his subsequent downward revision (Harris 1980) by 0.6 mag makes the difference larger still. This estimate relied on the level of the tip of the RGB which may be confused with the large number of foreground stars (Figure 4).

- Our determination of the cluster's metallicity, $[Fe/H] = -1.58 \pm 0.05$, confirms that it is a halo object. This measurement lies between the two previous determinations and is indicative of the trouble associated with crowded field spectroscopy. We feel that this determination of the metallicity using the CMD gives a more accurate picture of the general nature of the cluster with good discrimination possible between cluster and field stars. This metallicity is confirmed by a comparison of the fiducial sequence of NGC 6517 with clusters in the same metallicity range (see Figure 7) and by the blue HB, which is a characteristic of many metal-poor systems.

- Our newly-determined distance for NGC 6517 puts it *within* the Galactic bulge ($R_{GC} \sim 3.0$ kpc for R_0 in the range 8.0-10.0 kpc). We conclude, then, that NGC 6517 is a bulge globular cluster with an intermediate to low metallicity.

- The RGB of NGC 6517 is rather stubby. It is the third cluster in the bulge with such a feature (Janes & Heasley, 1991 and Stetson & West, 1994). This seems significant as only four bulge objects have CMDs of sufficient quality to distinguish this feature. Janes & Heasley (1991) suggest that the stubby RGB of NGC 6293 may be attributable to the fact that the cluster has undergone core collapse. If this is the case then NGC 6517 and NGC 6287 should also be investigated for possible core collapse. On the other hand, this truncated RGB may be indicative of

some other environmental influence within the core of the Galaxy.

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